02 | *BT16* Feedstock Assessment Methods and Select Scenarios

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2.1 Introduction

The purpose of this chapter is to provide a brief summary of the methodology used to generate the data described in volume 1 of the 2016 Billion-Ton Report (*BT16*); these data form the basis of the analyses presented in *BT16* volume 2. This chapter is not intended to be a comprehensive description of the volume 1 methodology. For details not addressed here, the reader is referred to the appropriate chapter and associated appendices in volume 1. Furthermore, only the agricultural (chapter 4) and forestry (chapter 3) feedstock assessments from *BT16* volume 1 are summarized in this chapter (sections 2.1 and 2.2 respectively). The final section of this chapter (2.3) summarizes the data selected from volume 1 that are used in volume 2. The methodology used to simulate algae biomass is described succinctly in chapter 12 of this volume. Finally, waste resources, which were components of the biomass in *BT16* volume 1, are described briefly in chapter 14, which addresses approaches to enhance environmental outcomes.

2.2 Agricultural Feedstocks

BT16 employs the Policy Analysis System (POLYSYS), a policy simulation model of the U.S. agricultural sector (De La Torre Ugarte and Ray 2000), to evaluate the potential farmgate supplies of dedicated energy crops and agricultural (conventional crop) residues. POLYSYS uses linear programming models of crop supplies, as well as demand and price components to recursively estimate annual supply, demand, price, and income of conventional and dedicated energy crops for each county in the conterminous United States. Hawaii and Alaska are excluded from the model because significant quantities of conventional crops are not grown in these states.

POLYSYS is a system of interdependent modules that simulate 1) county conventional and dedicated energy crop production; 2) national crop demands and prices; 3) national livestock supply and associated feed demand; and 4) agricultural income. Variables that drive the modules include the planted and harvested area, production inputs, yields, exports, production costs, usage demands, commodity prices, government program outlays, and net realized income. An important component of POLYSYS is its ability to simulate how commodity markets balance supply and demand via price adjustments based on assumed economic relationships (e.g., price elasticities). POLYSYS estimates how agricultural producers may respond to new market opportunities, such as new demand for biomass, while simultaneously considering the effect on conventional crops.

Conventional crops considered in POLYSYS include corn, grain sorghum, oats, barley, wheat, soybeans, cotton, rice, and hay, which together comprise approximately 90% of the U.S. agricultural cropland area. Pastureland is included as permanent pasture and cropland used as pasture. Residues from corn, grain sorghum, oats, barley, and wheat are also estimated. Dedicated energy crops include four herbaceous crops (switchgrass, energy cane, miscanthus, and biomass sorghum) and two classes of short rotation woody crops (SRWCs) (coppice and non-coppice). The SRWC classes are designated as either poplar or pine for the non-coppice class and as willow or eucalyptus for the coppice class because the species assignment of these categories is unique at the county level. However, these individual species are renamed to either coppice or non-coppice in the POLYSYS output data. POLYSYS livestock categories (which contribute to the demand for conventional crops as feed) include cattle, hogs, chickens, turkeys, milk cows, horses, sheep, and goats.

POLYSYS uses a baseline simulation approach in which simulations are anchored to an established baseline of projections for the agricultural sector, and the model simulates scenarios that reflect the impact of changes to the baseline (De La Torre Ugarte and Ray 2000). Linking a scenario to a baseline enables a user to only consider the effect of changes in the economic conditions of interest. For *BT16*, the specified scenarios focused on various offered prices for cellulosic-biomass products (dedicated energy crops and agricultural residues) combined with improvements in energy crop yields, variations in conventional corn yield, and the flexibility of conventional crops to switch among tillage classes. Additional details about the user-specified scenario assumptions are discussed below in section 2.1.2. Section 2.1.1 summarizes the important model inputs, assumptions, and constraints that form the basis of the POLYSYS simulations.

2.2.1 Model Inputs, Assumptions, and Constraints

Baseline: The simulation period for the *BT16* volume 1 agricultural feedstock estimates is 2014 to 2040. POLYSYS anchors its simulations to a baseline that consists of two parts. For the period 2014 to 2023, the 2015 10-year U.S. Department of Agriculture (USDA) baseline projections of crop and livestock

[2] Biogas from animal manures and landfills is analyzed in chapter 5.

supply and demand for the agriculture sector (USDA 2015) is used. Beyond 2024, the USDA baseline is used as an average (linear) trend, and POLYSYS adjusts demand levels and prices to equilibrium around this trend. This approach is used for all food, feed, fiber, fuel, and export variables beyond 2024 except for domestic ethanol and biodiesel demand, which are extended beyond the USDA baseline by holding the 2024 USDA baseline estimate constant. Domestic ethanol and biodiesel demands are held fixed because of the assumption that the renewable fuel standard is met and maintained at the statue level (including 5.2 billion bushels of corn grain to ethanol and 365 million bushels of soy to biodiesel) from 2024 through the remainder of the projection period. This baseline is termed the ‘’extended agricultural baseline” and simplified as the “agricultural baseline.”

Conventional Crops: National Agricultural Statistics Service (NASS) data from USDA are used to generate initial estimates of a county’s planted area, harvested area, harvested-to-planted ratio, and yield for the conventional crops modeled in POLYSYS. Data sources include annual survey data obtained from the NASS Quick Stats database (USDA-NASS 2015) and the geospatial Cropland Data Layers (CDL) (Boryan et al. 2011). The survey data are the primary source of county-level estimates of area and yield. However, in some states and for some crops, survey data are only reported for the NASS Agricultural Statistics Districts (ASDs). In those cases where only ASD-level estimates exist, county-level estimates are calculated by multiplying the ASD planted and harvested areas by the county crop fractions in the ASD based on the crop areas reported in the CDL. The ASD harvested-to-planted ratio and yield are assigned to a county in the ASD if the CDL reports planted area in the county. Four years (2010–2013) of data are averaged to reduce inter-annual variability, and these averages are then used as input by POLYSYS. POLYSYS adjusts the initial estimates of a county’s planted areas proportionally so that the sum of these planted areas matches the USDA baseline (USDA 2015) total of 312.6 million acres (including 57.9 million acres of hay).

Conventional crop planted area and yield are assigned to one of three tillage categories of management: no-till production, reduced tillage, and conventional tillage based on 4 years of historical data (CTIC 2007). Tillage-specific yields are estimated from the corresponding 4-year historical averages by applying regression models (Toliver et al. 2012).

Agricultural Residues: Quantities of removable agricultural residues are based on estimates of total aboveground biomass produced as byproducts of conventional crops, which are then limited by supply constraints (see *BT16* volume 1, appendix C; constraints that are applied for environmental purposes are described in chapter 1 of this volume). Total aboveground biomass residue produced (before operational and other supply constraints are applied) is calculated in POLYSYS based on ratios of residue to grain for corn, barley, oats, sorghum, and wheat as described in table C-3 of appendix C in *BT16* volume 1.

The POLYSYS supply constraint consists of a sustainability constraint and an operational efficiency constraint that are combined to estimate the harvestable yield of residue. The amount of residue that can potentially be removed is limited to the lesser of the two supplies. The harvestable yield is subsequently removed if the price offered exceeds the residue production cost. The residue production cost is only based on the additional operations needed to harvest the residues and replace the nutrients removed; the establishment and maintenance costs of the residues are included in the budgets for corresponding conventional crops. If harvesting is not profitable, the residues are not removed.

The sustainability constraint for residues is designed to limit residue removal to ensure that the tolerable soil-loss limit of the USDA Natural Resources Conservation Service (USDA-NRCS 2016) is not exceeded. This constraint also prevents long-term reduction of soil organic carbon. The Revised Universal Soil Loss Equation – Version 2, the Wind Erosion Prediction System, and the Soil Conditioning Index are used to calculate county-level average-retention coefficients for wind, rain, and soil carbon for each rotation and tillage combination (Muth et al. 2013).

Operationally available residues are limited to 50% of the total-county residue yield starting in 2015, increasing linearly to 90% of available residue yield in 2040 but not exceeding the sustainably available residues (see 4.2.3 and discussion of model sensitivity to operational efficiency under 4.8.6 in *BT16* volume 1). The operational constraint is a function of the total residue yield. This constraint reflects the near-term technical challenges of harvesting variable levels of residue, while allowing for future technological advancements in harvesting equipment that could mobilize greater proportions of the available residue supply.

Dedicated Energy Crops: Energy crop yields are empirically modeled using yields calculated from field trial data collected under the Sun Grant Regional Feedstock Partnership and coupled with climate data generated by the PRISM (Parameter-elevation Relationships on Independent Slopes Model) interpolation method (Daly et al. 2008). Following six crop-specific workshops, data from more than 110 Sun Grant field trials were used to estimate county-specific, per-acre yields using a specialized version of PRISM developed for *BT16* PRISM Environmental-Model (PRISM-EM) (Halbleib, Daly and Hanaway 2012). PRISM-EM is based upon the biweekly values of precipitation, minimum temperature, and maximum temperature estimated by PRISM, and Soil Survey Geographic (SSURGO) Database's soil pH, drainage, and salinity. It uses crop-specific water-use and temperature-tolerance relationships to estimate yield as a function of PRISM climate and soils data. Initial calibrations for these functions are based on known, relative tolerances for warm- or cool-season crops and whether they are grown as annuals or perennials. These functions are coupled with data on soil characteristics and historical weather patterns to generate "first-guess," average, annual relative-yield values (0%–100%). The relative values are regressed with average field-trial yield values to create a transfer function that is used to estimate absolute yield. Since yield data are available for only a few years, in some cases, PRISM-EM is run for the individual years that match those of the data. The estimated yields are adjusted to reflect those under 1981–2010, 30-year average climate conditions. The process of modeling relative yield and estimating absolute yield was done in an iterative fashion during meetings with species experts. In these meetings, yield outliers from the regression function were examined, and model calibrations were modified as needed.

All energy crops are modeled as perennials except for biomass sorghum, which is modeled as an annual crop. Switchgrass is assumed to have a stand life of 10 years with 50% of the expected mature yield potential in year 1; 75% in year 2; and 100% of the expected mature yield potential in years 3–10. Miscanthus has a stand life of 15 years with no harvest of potential yield in year 1; 50% of mature yield potential in year 2; and 100% in years 3–15. Energy cane has a stand life of 7 years with 75% of the expected yield potential in year 1 and 100% yield potential during the remaining years of the stand. Non-coppice SRWCs (poplar and southern pine) are grown on an 8-year rotation with harvest occurring in year 8. Eucalyptus, a coppice SRWC, is grown on an 8-year rotation with harvesting every 4 years. Willow, also a coppiced crop, is grown on a 20-year rotation with harvesting every 4 years. The SRWC rotation lengths were chosen to reflect the shorter time needed to grow these feedstocks for energy use as compared to use for conventional products.

Harvest efficiency factors are also applied to the potential yield to reflect the factor that the harvesting equipment cannot remove all of the available biomass. A harvest efficiency of 90% is applied for switchgrass, miscanthus and energy cane. A 95% efficiency factor is for the SRWCs.

Pasture and Idle Land: The initial value for area of pasture used in POLYSYS is the sum of the cropland used as pasture (11.2 m acres), permanent pasture (402.1 m acres) and other pasture (33.1 m acres) as defined by USDA-NASS (2014). Pasture must meet certain requirements to be eligible for energy crop production including: the land must be rain-fed (not irrigated), there must be additional pastureland of similar quality available for intensified management at a ratio of 1.5 acres for each acre to be used for energy crops; and it must receive 25 inches or more of annual precipitation. This area of pasture is estimated to be 47.1 million acres nationally. Pasture is further classified as either permanent pasture or cropland pasture based on the census data.

The initial estimate of idle land area is also obtained from the 2012 USDA Census Data (USDA-NASS 2014). Land enrolled in the Federal Conservation Reserve Program is included in this initial estimate, but these areas are excluded in POLYSYS from the land base available for conversion to energy crops. The 2015 estimate of idle land used in POLYSYS is 12.3 million acres. The estimate of idle land in the 2040 agricultural baseline projection is 23.2 million acres.

Land Base and Transition Constraints: The total agricultural land base within POLYSYS is fixed throughout the 2015 to 2040 projection period. The land base represents the combination of area in conventional crops, pasture and idle land, as explained above. Natural, reserved, and environmentally sensitive areas such as wetlands, grasslands, and protected forests, as well as all public lands, are explicitly excluded from the agricultural land base. Military lands, powerline cuts, and other areas on which biomass crops could grow are also excluded from the land base.

Although the total land base is fixed, land is allowed to change annually among tillage practices for a crop; the land can also transition among crops and pasture to satisfy baseline demands for conventional crops, while also maximizing profit for dedicated energy crops. Transitions are primarily driven by the expected productivity of land, crop production costs, the expected economic return on the crop, and market conditions. However, for perennial dedicated energy crops, once land is allocated to such a crop, it will remain assigned to that crop for the duration of the crop's rotation period.

Transitions among crops are limited by a 10% maximum annual county-level area change constraint. This constraint is coupled with a tillage flexibility index to control switching among the tillage classes for each conventional crop. The index, which is specified as an input to POLYSYS, can take a value of 1, 2, or 3. A tillage index of 3 allows up to 2.5 times more area to change than an index of 1 as the price for agricultural residues increases. Index values associated with the scenarios are presented below.

Transitions from pasture to energy crops are constrained by annual and cumulative limits that set the maximum percentage of land that can transition. The annual limits are 5% of permanent pasture and 20% of cropland pasture. Cumulative limits are 40% of permanent pasture and 40% of cropland pasture for all energy crops. The exception is biomass sorghum, which is constrained to USDA land capability classes I and II. The pasture conversion constraints are further bounded by a requirement that for each acre of pasture converted to an energy crop, another acre of pasture must be managed for intensified grazing. The additional costs needed for this intensification are used by POLYSYS to determine the economic viability of converting pasture to energy crops. Cumulative cropland conversion to dedicated bioenergy crops is also constrained to 25% of total acreage.

Idle land cannot move into energy crop production in the model simulations. It is accounted for in baseline calibration to determine where, geographically, annual changes in crop acreage in the agricultural baseline either come into or go out of production. Land no longer needed for crop production can transition into idle land and idle land can convert to conventional crop production if needed.

Equipment, Material, and Cost Budgets: A database and associated computer programs are used to estimate the production costs, equipment usage, labor, and material usage (e.g., fertilizer) for the conventional and dedicated energy crops and residues simulated in POLYSYS. Land rents are not included. The database contains individual equipment costs and attributes such as engine horsepower and capacity, and material attributes such as quantities and types of fertilizers and chemicals. The information is based on 2014 costs and operations obtained from various literature sources and subject experts. The database also specifies how these machines and materials are assembled into systems to determine total enterprise budgets. Budgets and material usage for residues only include the additional operations needed to harvest the residues and replace the nutrients removed since the establishment of the associated crop; maintenance costs of the residues are costed in the corresponding conventional crop budgets.

Except for one case, budgets for dedicated energy crops do not include irrigation. The exception is the budget for energy cane in the Imperial Valley of California. However, none of the POLYSYS scenarios analyzed in *BT16* volume 1 included the production of energy cane in California. Also, no Regional Feedstock Partnership field trials that were irrigated were used to estimate energy crop yields.

The agricultural budget database specifies detailed enterprise crop budgets for up to 13 POLYSYS Farm Resource Regions (FRRs), which, in turn, are based on the nine USDA FRRs (USDA-ERS 2000). The additional POLYSYS FRRs arise from splitting the USDA Northern Crescent and Southern Seaboard FRRs into two subregions each, and dividing the Fruitful Rim into three subregions. For conventional crops, budgets are specified for conventional tillage and no-till. Budgets for reduced-till conventional crops are assumed to be the same as the budgets for conventional tillage. The costs and material usage contained in the enterprise budgets are interpolated to ASD-level values for input into POLYSYS using an inverse distance weighting interpolation method (Hellwinckel et al. 2016).

2.2.2 Scenarios

An exogenous price simulation in POLYSYS (hereafter "specified price" simulation) specifies a farmgate price (dollars per dry ton)($/dt) for dedicated energy crops and residues as an input. Such a simulation represents the potential biomass production that could occur if a national market were in place beginning in the near term and offering constant prices until 2040. The specified price (in 2014 dollars) is adjusted for inflation and applied to all counties for all years in the simulation period. POLYSYS then solves for the allocation of land, which produces a mix of biomass that maximizes the profit in response to this price after first satisfying the fixed demands for food, feed, forage, fiber, biofuel, and exports. For example, at a $60/dt specified-price, the resulting supply in 2040 is achieved by the constant presence of a $60/dt market price in all preceding years (2015 to 2040 for residues and 2019 to 2040 for dedicated energy crops).

One base case (BC1) and three alternative scenarios (HH2, HH3, and HH4) were developed in BT16 volume 1 to represent a range of assumptions that incorporate variations in the specified price; flexibility in tillage and crop transitions; yield improvements in dedicated energy crops; and increased yield of corn grain (table 2.1). In all scenarios, planting of dedicated energy crops is not allowed until 2019, but residues are available for the entire simulation period (2015 to 2040). Additional information about the scenario assumptions is presented after table 2.1. A sensitivity analysis of these assumptions is provided in section 4.8 of *BT16* volume 1.

Independent POLYSYS simulations were run at specified prices ranging from $30/dt to $100/dt in $5/dt increments for all conventional crops, dedicated energy crops, and residues together. This approach allows each dedicated energy crop to compete with both conventional crops and other dedicated energy crops for land. It provides an integrated assessment of the potential biomass availability from a mixture of dedicated energy crops and residues under the specified scenario.

The large volume of generated data prevented analysis of the results for every specified-price simulation, so only the results from the $40/dt, $60/dt, and $80/dt results were analyzed in *BT16* volume 1. The results of the $60/dt simulations from the base-case (BC1) and intermediate high-yield (HH3) scenarios were selected for analysis in *BT16* volume 2. The $60/dt-specified price was selected as an economically realistic price level.

Table 2.1 | Description of Agricultural Scenarios Analyzed in Volume 1 (Scenarios Used in Volume 2 Are Shown in Bold)

Scenario identifier	Description	Specified prices for energy feedstocks	Tillage flexibility constraint	Energy crop yield improvement (annual)	Conventional crop yields
BC1	**Base case (1%)**	$40, **$60**, $80	**1**	**1%**	**Baseline for all crops**
HH2	High yield (2%)	$40, $60, $80	3	2%	High corn grain, baseline for all other crops
HH3	**High yield (3%)**	$40, **$60**, $80	**3**	**3%**	**High corn grain, baseline for all other crops**
HH4	High yield (4%)	$40, $60, $80	3	4%	High corn grain, baseline for all other crops

Additional details regarding the scenarios are presented below.

Tillage Flexibility Constraints: As mentioned above, the tillage flexibility constraint controls the amount of land that changes tillage class annually for a given conventional crop. A tillage index of 3 allows up to 2.5 times more area to change than an index of 1, subject to an overall maximum annual change constraint of 10%.

Energy Crop Yield Improvements: Base-case and high-yield scenarios represent possible yield improvements over time that may be achieved with a mix of improved management practices and crop genotypes. These assumptions are derived from a series of workshops in 2010 drawing on expert opinion (INL 2009). Yield improvements are applied and compounded annually beginning in 2015.

Conventional Crop Yields: Yields for all conventional crops except corn are set to match their respective agricultural baseline values over the simulation period. For BC1, corn yield is also kept at its baseline values, but for HH2, HH3, and HH4, the corn yield is allowed to increase more rapidly to reach a national target of 265 bushels per acre in 2040. This increased yield allows for greater adoption of no-till management and a greater production of corn residues.

2.3 Forestry Feedstocks

The linear programming Forest Sustainable and Economic Analysis Model (ForSEAM) is used to estimate roadside forestland production over time to meet demands for both traditional forest products and biomass feedstock. The biomass feedstocks include forest residues and whole trees harvested explicitly for biomass uses. Wood wastes from sawmills and from landfills (e.g., construction and demolition waste) are not estimated by ForSEAM.

ForSEAM can be used to estimate the quantity of biomass that might be available as energy feedstocks for 305 production regions that correspond to the NASS ASDs (He et al. 2014). The model also estimates costs, land use, and competition among lands. ForSEAM seeks to determine the mix of harvested stand types that minimizes total cost (harvest and other costs) under a production demand target for wood products and biomass. The model requires that projected traditional timber demands be met first (i.e., traditional timber demands are fixed across scenarios). The mix of stand types used to meet the demand is subject to land, growth, and other constraints. The model estimates production based on location, stand type, stand's average tree diameter, slope of the land on which the stand occurs, harvest method, type of product that will be produced, and time of harvest. Regional model results are disaggregated to the county level using the ratio of the county planted area to the regional total planted area, calculated from the Forest Inventory and Analysis (FIA) program database (USDA-FS 2015).

ForSEAM requires estimates of projected demands for sawlogs and pulpwood. These demand levels are obtained from the U.S. Forest Products Module (USFPM) (Ince et al. 2011a). The USFPM is a global, forest-products, partial-equilibrium market model that operates within the Global Forest Products Model. USFPM provides detailed information on forest products production, trade, and prices for the North, South and West (see chapter 3 in BT16 volume 1) regions of the conterminous United States. In USFPM, wood energy demand can compete for supply sources also used to make lumber, panels, and paper; forest inventory responds to harvest and growth. U.S. demand for wood energy is specified at the national level, and the model determines the fuel feedstock-supply allocation among the North, South, and West regions by using the lowest-cost feedstock sources to meet the national demand. The U.S. demand for wood energy includes demands for residential and industrial fuel wood, as well as the potential for increased demand for wood pellets for export, and/or assumed domestic demands for biopower and biofuels. Weights based on inventory are used to develop state estimates of demand for these traditional wood products, which then serve as input for ForSEAM.

2.3.1 Model Inputs, Assumptions, and Constraints

Stand Types and Characteristics: Five stand types are simulated in ForSEAM: upland hardwood, lowland hardwood, natural softwood, planted softwood, and mixed wood. For each stand type, three diameter sizes are modeled: class 1 (stands with diameter at breast height (dbh) of >11 inches for hardwood and >9 inches for softwood); class 2 (stands with dbh between 5–11 inches for hardwood and dbh between 5–9 inches for softwood); and class 3 (stands with dbh <5 inches).

For the initial simulation year, clearcut yields are calculated using information on standing tree volume and corresponding timber area from the FIA database aggregated to the county level. The thinning yield is 70% of the clearcut yield, assuming a combination of thinning-from-above (Coops et al. 2009; McMahon 2016) when harvesting conventional products and only taking the smaller-diameter trees when harvesting whole trees for biomass.

If stand types in classes 2 and 3 are not harvested, they continue to grow and become class 1 and class 2 stands respectively, depending on the annual increment of quadratic mean diameters for that stand type. If class 2 stands are harvested by thinning, they are not available for additional harvesting until they become class 1 stands. Annual growth yield is based on the net annual growth and the corresponding timber area. For all years beyond the initial year, the yield is assumed to be the initial yield, plus the total growth yield, multiplied by the total numbers of years from the beginning to the current simulation year.

USFPM estimates five timber products including softwood sawlogs, softwood pulpwood, hardwood sawlogs, hardwood pulpwood, and other industrial roundwood. The demands for hardwood sawlogs and other industrial roundwood are aggregated to hardwood sawlogs in ForSEAM. The roundwood harvested for fuel is disaggregated to softwood and hardwood fuel wood, using a ratio calculated with data from Howard, Quevedo, and Kramp (2009). In ForSEAM, sawlogs originate from class 1-size trees. Pulpwood originates from trees in size classes 1 and 2. Whole-tree biomass feedstocks are from trees in classes 2 and 3. The volume of hardwoods (lowland and upland) and 37.5% of mixed wood stands are used in the model for hardwood timber products. The volume of softwood (natural and planted) and 62.5% of mixed wood stand species is used for softwood timber products.

Whole-Tree Harvest: There are four combinations of harvest methods and intensity for whole trees: 1) full-tree clearcut, 2) full-tree thinning, 3) cut-to-length clearcut, and 4) cut-to-length thinning. The full-tree method can use the entire tree, including branches and tops. The cut-to-length method harvests logs only, leaving logging residue behind. For both methods, the intensity can be either clearcut or thinning. Clearcutting removes all of the standing trees in a selected area. Thinning removes part of the standing trees in a selected area.

Annual harvesting intensity is limited to 5% of the amount of timberland area within a ForSEAM region. Also, the harvest intensity is restricted at the state level to ensure that growth exceeds harvest removals. Together, these two factors prevent the model from harvesting more wood in a region than can be grown based on the corresponding state's growth rate. The value of 5% is estimated by taking the potential production compared with the 2010 projected demand estimated by the USFPM. This value was found to be sufficient to meet the future conventional wood demand.

Only class 2 stands may be harvested by clearcutting or thinning. Cut-to-length is used only for softwood timber in the North Central and Inland West regions for class 1 and class 2 stands. No harvesting is allowed on lands with a slope >40% in the Northeast, South, North Central, and Inland West regions since it is assumed that cable harvesting systems are not available in these regions. ForSEAM assumes that only in the Pacific Northwest trees can be harvested for conventional products on timberlands in both slope classes (≤40% and >40%).

A constraint for clearcut and thinning areas was applied in the West, South, and North (see chapter 3 in *BT16* volume 1) to ensure that a certain amount of production was excluded from thinning. This constraint is included because the benefits of thinning, such as increased yields and revenue, are hard to measure and capture at the scale of the current model. In the model, the clearcut portion is 42%, 28%, and 10% for the West, South, and North, respectively.

The timberland constraints built into ForSEAM limit harvested timberland for conventional wood to the maximum percentage of the existing volume of class 1 land that can be harvested in any one period. Other constraints limit the harvest intensity to the existing volume of classes 2 and 3. The third timberland constraint requires cut-to-length harvest acres to equal full-tree harvesting acres in the North Central region and Inland West region. A major timberland constraint restricts logging residue removal to those lands that provide traditional products; growth is also restricted. The volume of trees removed must be less than the 2014 base-year harvest plus the annual growth that occurs within the state on the remaining stands to ensure that harvest never exceeds growth.

Logging Residue Removal: Not all available logging residues are harvested for biomass feedstock use. A retention rate of 30% is applied to residues from clearcut, full-tree harvesting on timberland with a slope of ≤40%. If the available logging residues are from stands located on timberland with a slope of >40%, all of the logging residues are left on the site. If the timberland is thinned (partially cut), 30% of the residues are retained on-site, (i.e., a 30% retention rate) if the slope is >40%. All logging residues from thinned stands are available for harvesting as biomass feedstocks in the model if the slope is ≤40%. The underlying assumption is that residues will still be left on-site because of tree breakage and losses from harvesting trees and that the remaining trees will provide sufficient protection from soil erosion and loss of soil organic carbon.

Land Base and Transition Constraints: To be consistent with the agriculture assessment, only production in the conterminous United States is estimated. Total forestland in the conterminous United States is 623 million acres. Timberland is defined as forestland that produces more than 20 ft^3 per acre of industrial wood annually where harvesting is not prohibited. There is 475 million acres of timberland in the conterminous United States.

The land base for ForSEAM modeling only includes timberland that is classified as nonreserved federally or privately owned and is no more than 0.5 mile from an existing road system. Data from the FIA program database indicate that about 300 million acres of privately owned timberland and approximately 87 million acres of federal lands meet this definition (387 million acres total). The available land base is also categorized into two ground slope classes: 1) slope ≤40% and 2) slope >40% based on the FIA database.

After timberland is clearcut, replanting occurs if the stand was originally classified as planted softwood, and natural regeneration occurs if the stand is one of the other four types. All stands are assumed to replant or regenerate in the same stand type (e.g., natural hardwoods regenerate back to natural hardwood forests).

Equipment, Material and Cost Budgets: A database and associated computer programs based on information from the Consortium for Research on Renewable Industrial Materials (CORRIM) (Oneil and Lippke 2010; Johnson et al. 2005) are used to estimate the harvest equipment, labor, materials, and costs used in ForSEAM. The database contains individual machine costs and attributes such as engine horsepower, capacity, and operation (e.g., felling). The database specifies how these machines are assembled into systems to determine total budgets. Harvest systems and budgets are estimated for each feasible combination of stand type; stand diameter class; ground slope class; harvest method (full tree or cut-to-length); harvest intensity (clearcut or thinning); and product (merchantable products of sawlogs and pulpwood, logging residues; and whole-tree biomass) in five regions (Northeast, North Central, South, Inland West, and Pacific Northwest). The 2004 CORRIM equipment costs are updated to 2014 prices using the Producer Price Index for construction machinery manufacturing (Bureau of Labor Statistics 2015).

Stumpage prices are based on the RISI (2008) international wood fiber report data. The pulpwood price is used as the stumpage price for hardwoods and softwoods stands in class 2. For mixed wood, the price is calculated as 37.5% of the hardwood stumpage price plus 62.5% of the softwood stumpage price. For each stand species, the stumpage price of a class 1 stand is twice that of a class 2 stand. The class 3 stand stumpage price is 50% of the class 2 stand price. If logging residues are collected from the harvested site, their stumpage price is the fraction of the whole-tree stumpage price. The price is based on the ratio of the residue yield to the whole-tree yield, using the FIA database to calculate that value. Price data for hardwood, pulpwood, and roundwood in the West region are not available. In these cases, the 2007 estimate of $23.48 per dry ton for hardwood in the West is used.

2.3.2 Scenarios

Six scenarios are used in *BT16* volume 1 to evaluate U.S. forest-product market outcomes for three levels of national wood-biomass feedstocks demand, two levels of housing recovery, and two levels of southern pine-plantation growth rates (table 2.2). In all scenarios, 1) U.S. demand for solid wood products is driven by projected growth trends in U.S. real gross domestic product (GDP) and single-family housing, and 2) U.S. demand for paper products is driven by real GDP and by recent historical growth rates for advertising expenditures in print media and electronic media (Ince et al. 2011b). Net exports of U.S. forest products are influenced by projections of global demand for forest products and projections of global currency-exchange rates. All scenarios use the 2012 USDA Economic Research Service global projections for GDP and currency exchange rates for all countries to 2030 (USDA-ERS 2015).

The baseline scenario represents moderate housing and low wood energy demand (scenario identifier ML in Table 2.2). It is derived from Ince and Nepal (2012), which assumes a moderate rebound in housing starts. The wood energy demand, which increases by approximately 26% between 2010 and 2040, is estimated by the historical econometric relationship between fuelwood consumption and GDP growth (Simangunsong and Buongiorno 2001). The five alternative scenarios shown in table 2.2 (HL, MM, HM, MH, and HH) vary in housing starts and wood energy demand. Additional information about the assumptions is presented after table 2.2.

For each scenario, ForSEAM was run at specified-biomass demand levels ranging from 1 million dry tons (Mdt) to approximately 185 Mdt in increments of 1 Mdt. Logging residues to meet the specified biomass demand are available only when trees are harvested for conventional timber markets. When those markets are saturated, logging residues are no longer available as a source of biomass. Logging residues are assumed to be harvested as an integrated product, along with the conventional sawlogs and pulpwood, at a relatively low extra cost compared with whole-tree biomass. Therefore, all available logging residues are harvested first in the model to meet the specified biomass-demand level. When the demand is greater, then the model solves for the lowest-cost whole-tree biomass to supplement the demand.

The large volume of data generated by this approach prevented analysis of the results for every simulated demand level. Instead, the highest specified-demand run that had a solution in all years of each scenario was selected to provide a representative estimate of production and harvested acreage. The selected biomass-demand level for each scenario is shown in parentheses in table 2.2.

Table 2.2 | Description of Forestry Scenarios Analyzed in *BT16* volume 1 (Scenarios Used in Volume 2 Are Shown in Bold)

Scenario identifier	Description	Specified biomass demand levels	Housing starts	Wood energy demand
ML (baseline)	**Moderate housing–low wood energy**	1 to 187 Mdt **(116 Mdt)**	**Returns to long-term average by 2025**	**Increases by 26% by 2040**
HL	High housing–low wood energy	1 to 187 Mdt (117 Mdt)	Adds 10% to baseline in 2025 and beyond	Increases by 26% by 2040
MM	Moderate housing–moderate wood energy	1 to 184 Mdt (93 Mdt)	Returns to long-term average by 2025	Increases by 86% by 2040
HM	High housing– moder-ate wood energy	1 to 184 Mdt (94 Mdt)	Adds 10% to baseline in 2025 and beyond	Increases by 86% by 2040
MH	Moderate housing–high wood energy	1 to 184 Mdt (82 Mdt)	Returns to long-term average by 2025	Increases by 150% by 2040
HH	**High housing– high wood energy**	1 to 184 Mdt **(83 Mdt)**	**Adds 10% to baseline in 2025 and beyond**	**Increases by 150% by 2040**

Housing Starts: Moderate housing starts assume a rebound in housing, with average single-family housing starts increasing to the long-run historical trend of 1.09 million per year by 2020 and following a slowly increasing trend thereafter. The high housing option assumes starts would be 10% higher by 2025 and would stay 10% higher throughout the projection. The top quartile of housing starts from 1959 to 2011 is at least 10% above the long-term average, indicating that the higher rate is feasible.

Wood Energy Demand: As discussed above, low wood energy demand is estimated by the historical econometric relationship between fuel wood consumption and GDP growth (Simangunsong and Buongiorno 2001). The moderate and high wood-energy demand scenarios represent increases in domestic and/or pellet export wood-energy demands that are not captured in the historical relationship between fuel wood use and GDP (Abt et al. 2014). The moderate wood-energy demand scenario is estimated as a quadratic demand function that incorporates the announced production facilities in the Forisk Consulting wood energy database through 2020 (Forisk Consulting 2014) and an increase based on continued pellet exports. The high wood-energy demand scenario assumes that production in 2020 will be twice as high as in the moderate scenario.

2.4 Environmental Effects Assessment

2.4.1 Farmgate and Landing Supplies

All of the *BT16* volume 2 environmental effects assessments use farmgate or forest landing estimates of agricultural and forestry supplies, respectively. Only a subset of the agricultural and forestry assessment scenarios and projection years are selected for use in the *BT16* volume 2 analyses. The scenarios are selected to represent a near-term base case (2017), a long-term base case (2040) and a long-term high-yield projection (2040). The $60/dt price runs from the BC1 and HH3 scenarios (table 2.1) were chosen from the agricultural assessment for the base-case and high-yield projections. Thus, the three agricultural scenarios addressed in this volume are BC1 2017, BC1 2040 and HH3 2040. The 3% annual yield increase scenario was selected over the 4% annual yield increase scenario because the former was considered more conservative. Annual county-level data sets containing simulation results for planted area, harvested area, production, and yield for conventional crops, residues, and dedicated energy crops were created for the selected scenarios. Of these scenarios, adjustments were made to exclude wastes and add conventional biofuels (see table 1.1 of *BT16* volume 1).

From the forestry scenarios in *BT16* volume 1, the baseline (ML) and high housing-high wood energy (HH) scenarios were selected for analysis in volume 2 (table 2.2). Thus, the three forestry scenarios addressed in this volume are ML 2017, ML 2040, and HH 2040. Annual county-level data sets of harvested area and production by stand type, material type (residue or whole-tree), size class, harvesting method, slope class, and land ownership for conventional wood products and bioenergy usage were created for the selected scenarios. As mentioned above, only results for the selected demand level were included (table 2.2).

In addition to the area and production data from the select scenarios, selected data from the agricultural budget databases were provided to some of the *BT16* volume 2 investigators. The data included equipment characteristics (e.g., horsepower, fuel usage) and quantities of fertilizers and chemicals applied to establish, maintain, and harvest the conventional crops, energy crops, and residues. Harvest equipment characteristics were provided from the forestry budget database.

2.4.2 Attribution

In the case of agricultural and forest residues, attribution of environmental effects can theoretically by applied to the primary crop (e.g., corn grain, sawtimber), the residue (e.g., corn stover, logging residues) or a combination of the two. In this volume, decisions on attribution of residues vary by chapter, and are specified below in table 2.3.

Table 2.3 | Specification of Attribution of Environmental Effects Between Residue Removals and Primary Biomass Broducts (Effects Are Attributed Entirely to the Biomass Removal for Energy Crops and Whole-Tree Harvests)

Indicator	Chapter	Attribution
Greenhouse gas emissions (agricultural and forest residues)	4	Agricultural residues burdened with emissions from harvest and supplemental fertilizer. Forest residues burdened with 10% of emissions per *BT16* volume 1 approach to costing.
Water quality (agricultural residues)	5	Loadings attributable to primary crop, residues, and energy crops on areas harvested for biomass.
Water quality (forest residues)	6	Loadings attributable to biomass harvest where whole-tree biomass harvests occur. Assumed that there would be negligible incremental impacts from removing residue after harvests, therefore they were not considered in the analysis.
Water yield (forests)	7	Yield attributable to biomass harvest.
Water consumption footprint (agricultural and forest residues)	8	Consumption attributable to primary crop and biomass harvest.
Air emissions (agricultural and forest residues)	9	Emissions from production attributable to primary product; emissions from harvest activities allocated between crop and residue; additional chemical and nutrient applications to replace nutrient removal attributable to the residue.
Biodiversity (agricultural residues)	10	Not applicable. Residue removal not considered.
Biodiversity (forest residues)	11	Changes attributable to residue removal.

2.4.3 Inter-Annual Crop Transition Estimates

Some of the *BT16* volume 2 analyses using the agricultural scenarios also required estimates of inter-annual and cumulative crop transitions. POLYSYS generates files that contain county-level estimates of inter-annual changes of crop-planted areas that correspond to the county-level production estimates. Using these data, we generated interannual county-transition proportions (e.g., 2020–2021) by dividing the changes in county crop-planted area by the total planted area in each county. Expressing the changes as proportions allows for the calculation of multi-year transitions by multiplying the corresponding inter-annual proportions (e.g., multiply 2020–2021 proportions by 2021– 2022 proportions to obtain 2020–2022 proportions). These results provide estimates of cumulative changes in crop-planted areas for each county.

2.4.4 Supplies Delivered to Biorefineries

Some *BT16* volume 2 analyses include a subset of the results from the delivered supply[1] analysis described in chapter 6 of *BT16* volume 1. To summarize, this analysis used a geographically based modeling system to allocate feedstock supplies to potential utilization facilities and calculate the delivered price and

[1] Supply is delivered to the throat of the biorefinery. Simulations are made for biochemical and thermochemical conversion platforms, so future products and conversion processes are not considered in this analysis.

quantity of the supplies (Webb et al. 2014). Costs of unit operations (storage, size reduction, and handling) and dockage (additional charges incurred for disposal of feedstocks that do not meet quality specifications) are derived from previous studies (Cafferty et al. 2014; Kenney et al. 2014). Locations of utilization facilities are based on minimizing the average total delivered feedstock cost. Facility locations are selected iteratively, in order of increasing total delivered cost, until all of the available supply is used.

For each feedstock, five logistics costs are estimated: (1) production costs; (2) other logistics costs (storage, handling, and preprocessing); 3) time transportation cost; (4) distance transportation cost (loaded), and (5) distance backhaul cost (empty). Production costs include operations on the farm (agricultural feedstocks), at the roadside (forestry feedstocks), or at the sorting facility (wastes), along with the grower payment (agricultural feedstocks) or stumpage price (forestry feedstocks). For agricultural biomass, a cost curve was generated from the $60 simulation for the base case and 3% high-yield scenario to represent the production of biomass at varying prices (see chapter 6 of *BT16* volume 1). The farmgate agricultural biomass cost includes production, maintenance, harvesting, and an assumed 10% profit per ton of biomass. Roadside forestry biomass cost includes stumpage and harvesting. Transportation cost is divided into time- and distance-based components. The distance component of transportation cost, namely fuel, varies by the distance traveled. The time cost accounts for the capital cost of the truck and labor cost. Fuel economy is known to change with payload, so distance transportation costs are estimated for fully loaded trucks going to the facility and for empty trucks on the backhaul. The other logistics cost parameter includes the costs of all other operations, such as storage, handling, and preprocessing. The final delivered supply is characterized as the quantity and combined weighted average cost by feedstock at the county of origin for the specified scenarios. The county estimates of feedstocks transported and the associated transport distances are provided to the *BT16* volume 2 investigators requiring such data.

Biomass delivered at prices up to $100 per dry ton was considered to be economically feasible given the uncertainty in simulation results and the potential for reducing logistics costs with technology improvements. Thus, energy consumption and emissions for biomass logistics were considered only for biomass with delivered costs up to $100 per dry ton.

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